Does Weather Affect Mental Well-Being Neurologically?

Bachelor Degree Project in Cognitive Neuroscience
Basic level 22.5 ECTS
Spring term 2018

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Abstract

Research on well-being is in its infancy and the term lacks a clear definition, yet it is an increasingly popular matter. The neurology underlying well-being is important in such research in order to understand what brain mechanisms are correlated with mental health. Even though objective measures such as brain imaging are increasingly used assessments in well-being and neuroscience studies, self-reports are widely used. Articles viewing such research often state that self-reports could be biased because the subjects may be affected by the weather the day of the self-report. No further explanations are however provided as to why or how those individuals would be affected by the weather, or by which weather conditions. The aim of this thesis is thus to find neurological explanations for how weather can affect well-being. Constituents of well-being will be reviewed together with brain bases of mental health in an attempt to find neural correlations of weather and well-being. How humans are affected by the weather is a limited research area and the findings are diverse on all aspects but the solar influence over the brain and mind. Man-made light was however found to be a substitute for the effect of sunlight on the brain. No strong relationship between weather and well-being were found based on existing literature. No significant neural correlations between mental well-being and different weather conditions was found either.

Keywords: well-being, mental health, neuroscience, weather, sunlight, meteorological impact, solar influence, neural correlates
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Introduction

It seems to me as though humans in general are drawn to sunshine and warmer degrees and personally I thrive in the sun. Living in Sweden, the few warm summer days we have are not only by me but also by my fellow residents utilized to the outermost. Although, as a citizen of one of the coldest and darkest countries in the world it is hard to tell if the weather conditions of Sweden per se is the reason for carving sunshine, and also whether it is the sunshine itself that makes us happier or if it is for example due to higher temperatures. That is why I left Sweden and went to visit my aunt in Dubai for six weeks, to constitute my own subjective experience of how the sun affects my well-being while writing this essay.

The original question for this essay was: How does weather affect mental states? A question that has haunted me since I became a student in cognitive neuroscience and positive psychology ((PP) the study of well-being). Numerous articles regarding mental health and neuroscience state that self-report measures used in such studies may not be accurate because the individuals rating themselves could be affected by the weather of that day (Connolly, 2013; Davidson, 2004). When originally seeking information about this question I tried to find neurological explanations for meteorological influence over the mind. However, the existing research regarding how the psyche is affected by weather is very limited and the findings are diverse. Moreover, the only neurological connections to weather conditions I could find were solar influence on the brain (Hasegawa & Arita, 2014). Hoping to get a better understanding of how the weather can affect self-report measures, the solar influence on the brain and mental health will be investigated. In order to understand this the underlying brain mechanisms of well-being need to be addressed first.

Well-being is a concept with more than one description and not all researchers agree on the conceptualization of well-being (Seligman & Csikszentmihalyi, 2000). Mainly wellbeing is divided into psychological well-being (PWB) and subjective well-being (SWB) with different components of what well-being consists of in both concepts (Ryff &
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The term well-being, which sometimes is used interchangeably with ‘happiness’, is widely used within the field of PP (Diener, 2000). PP is a relatively new area of research within the field of psychology (Sheldon & King, 2001). What makes life worth living can be used as a short interpretation of what PP studies (Urry et al., 2004). Since World War II the science of psychology has been dominated by psychopathology (mental illness) (Seligman & Csikszentmihalyi, 2000) and PP arose as an obverse to allow for psychological conditions of the mentally healthy part of mankind (Gable & Haidt, 2005). In current studies on well-being, self-reports have up until recently been the major assessment used as measurement of individual happiness (Sandvik, Diener, & Seidlitz, 1993). Although, as mentioned in Davidson (2004) self-reports used as measurement of people's well-being are not always reliable due to other variables (such as the weather) affecting those people the day of the self-report. Hence the search for objective measures is of importance and researchers have begun to commence this matter through various brain imaging techniques (Davidson, 2004; Oswald & Wu, 2010).

The neuroscience of well-being is in its infancy (Kringelbach & Berridge, 2009) but consistent findings show that greater relative left than right prefrontal neuronal activation is correlated with lower levels of negative affect (NA) and higher levels of positive affect (PA) (Sutton & Davidson, 1997). Though, relative greater left prefrontal cortical activation is also related to approach-oriented behavior as opposed to relative greater right side activation which is related to withdraw-oriented behavior, which could be the underlying reason for higher versus lower levels of PA and NA (Urry et al., 2004).

The existing research literature on how well-being is affected by the weather is diverse and inconsistent (Holick, 2016). In one article about weather and emotional distress it was concluded that as sun time increased with the seasons people's mental health distress decreased (Beecher et al., 2016). Another article, examining subjective measures of wellbeing in relation to daily sunshine, indicates that some assessments of well-being are
correlated to some types of weather such as for example sunshine and job satisfaction. The article also points out that the weather's effects on SWB are very little in general (Buscha, 2016).

Light from the sun is however what regulates an internal clock in humans which controls the sleep/wake cycle. This cycle is the circadian rhythm and it is orchestrated by the suprachiasmatic nuclei (SCN), a cerebral architecture that is connected to a visual pathway through which the light enters the brain (Reppert & Weaver, 2002). The circadian rhythm is a fundamental mechanism in humans but there is a mental disorder related to this function named seasonal affective disorder (SAD). Abnormalities in the SCN could result in the disorder and thereby cause a season related depression. It occurs annually during the same season every year and most commonly during the winter when solar light is the least (American Psychological Association, 2016). SAD was first addressed by Rosenthal et al. (1984).

Humans have always been exposed to the sun as well as evolved with it (Kastan & Bartek, 2004). Effects of the sun can be damaging but they can also be healthy. There are beneficial effects induced by the sun for humans to function normally and lead healthy lives (Holick, 2016). However, overexposure to the sun can be dangerous and even deadly (Armstrong & Kricker, 2001). One of many such direct problems due to lack of sun exposure is a disease called rickets which cause skeletal defects and growth retardation (Holick, 2003). This became a huge problem in relation to the industrial revolution for children living in big cities across Europe who developed the disease. In the early 19th century it was discovered that rickets was due to lack of sunlight, and thought to be because of tall buildings in between which the sun did not access. In the early 20th century came the conclusion that exposing those children possessing rickets to sunshine was an effective treatment. With regards to this the U.S. government encouraged the population in the 1930s to sunbathe their infants. Presumably as a result of vitamin D intoxication some of these kids
developed a condition called hypercalcemia, expressing itself in form of heart problems and mental retardation among other symptoms, in the late 40s and early 50s (Holick, 2016). The past few decades media have emphasized the problem of tanning because of skin cancer caused by too much sun exposure (Holick, 2016) and yet people do not protect themselves well enough (Heckman, Egleston, Wilson, & Ingersoll, 2008). Heckman et al. (2008) explain that 50 percent of all individuals with cancer in the U.S. suffer from malignant melanoma (skin cancer) and 90 percent of those cases are caused by ultraviolet radiation from the sun. Recent findings suggest that tanning could be an addictive behavior (Kourosh, Harrington, & Adinoff, 2010).

Relevance

The influence of the weather over the mind is important to illumine because researchers in neuroscientific articles so vastly mention that self-reports can be affected by the weather without any further explanations (Connolly, 2013; Davidson, 2004). Light from the sun is important from a neurological perspective since it regulates the circadian rhythm and too little exposure to sunlight during wintertime can cause season related depression (American Psychiatric Association, 2017). The amount of sun exposure is also significant to this topic since overexposure can cause mental retardation (Holick, 2016). In worst case scenario solar overexposure can lead to melanoma (skin cancer) and potentially death (Elwood & Jopson, 1997). Though, since there are only a few contemporary studies conducted on the topic of tanning addiction it is unsure if excessive UV endeavor, potentially causing melanoma, is due to neurobiology or a result of fashionable preference for tanned skin (Fell, Robinson, Mao, Woolf, & Fisher, 2014). Research on how the sun and other meteorological phenomena can affect mental well-being from a neurological perspective adds to the neuroscience of well-being.

Present study
Research on the neural correlates of well-being is in its infancy although there is already quite a vast literature regarding the area (Diener, 2000; Seligman & Csikszentmihalyi, 2000). Underlying brain mechanisms of mental health have been and continues to be explored and measured by objective measures such as brain imaging assessments (Davidson, 2002; Urry et al., 2004). Many of the studies regarding well-being and neuroscience that contain some sort of self-report measure, state that a confounding variable affecting the result could be the weather (Connolly, 2013; Davidson, 2004). None of such articles (that I have ever come across) explains why those self-reports would be biased by the weather or how the brain mechanisms underlying that would work. Currently there is very limited existing literature on how the weather really affects well-being but a consensus seems to be solar effects on mental health (Beecher et al., 2016). This can possibly be explained by the circadian rhythm controlled by the SCN. Lack of sunlight can cause dysfunction of the SCN and result in SAD (Rosenthal et al., 1984). While overexposure to the sun can cause a “tanning addiction” which is a new area of research and have not yet been acknowledged as a mental disorder (Petit, Lejoyeux, Reynaud, & Karila, 2014).

The aim of this essay is to find neurological explanations for how weather can affect mental health. This is done through systematic investigation of peer-reviewed articles retrieved from Web of science and Google scholar on neural correlates of well-being, weather effects on mental states, and solar influence on the brain.

This essay will open with a presentation of the term well-being to give an understanding of the concept. Theories behind and definitions of well-being are presented together with a brief insight into the field of PP where well-being is greatly studied. This is followed by the neuroscience of well-being. The influence of the weather on mental health is thereon examined and accompanied by the neural bases of how the brain is affected by sunlight. Indirect effects of the sun on the brain and well-being are then taken into account in
a biological framework explaining what vitamin D does for the body. The results are finally discussed to then be summarized in a conclusion of the central findings.

Well-Being: Theories and Definitions

Enhancing well-being among people and finding ways to do so is the purpose of the newly developed branch of PP but because of the fields’ recent birth different incoherent definitions have been made concerning what well-being really is (Kim-Prieto et al., 2005; Seligman & Csikszentmihalyi, 2000). Not all of those definitions are in agreement of the constituents composing well-being but a consensus is that well-being is not only the absence of mental illness (Seligman & Csikszentmihalyi, 2000).

Two definitions of well-being are the concepts eudaimonic well-being and hedonic well-being (Deci & Ryan, 2008). Other terms used to explain almost the same matters are SWB and PWB where, in some cases, SWB have been used interchangeably with hedonia and PWB have been used interchangeably with eudaimonia (Deci & Ryan, 2008; Ryff & Singer, 2008). SWB is defined as momentary moods judgements and satisfaction with life evaluation based on the individuals own experience, and the main concern here is peoples self-evaluation of their lives (Kim-Prieto et al., 2005). It has been noted that SWB possess the same characteristics as hedonia. Hedonic well-being is characterized by greater PA than NA (Deci & Ryan, 2008). In Ryff and Singer (2008) eudaimonic well-being is explained as PWB and they narrates PWB as being made up of six different aspects. These aspects are selfacceptance, purpose in life, environmental mastery, positive relations with others, personal growth and, autonomy (Ryff & Singer, 2008). Eudaimonia dates back to Aristotle and have been of great interest for researchers in addition to SWB (Deci & Ryan, 2008; Ryff & Singer, 2008).
Eudaimonia and hedonia have previously been dealt with as two completely different phenomena due to their different criteria for well-being. However, more recent research indicate that the two conceptualizations stem from philosophy and is not necessarily applicable in science (Kashdan, Biswas-Diener, & King, 2008). Kashdan et al. (2008) argues that the assessments used to measure eudaimonia lacks consistency and that eudaimonic wellbeing is not defined enough. In their article Kashdan et al. (2008) also states that the concepts of eudaimonia and hedonia overlap, and that they may represent psychological functions which operates together. This is in line with what Kringelbach & Berridge (2009) concluded about hedonia and eudaimonia. They found that the majority of people who are high in eudaimonia are also high in hedonia and hence propose that the two phenomenons of wellbeing are more coupled than what have previously been accounted for (Kringelbach & Berridge, 2009). Trying to figure this out and distinguish between concepts to make clear definitions of well-being is a major concern within PP (Diener, 2000).

**Positive Psychology**

The field of PP is a quite new one (Seligman & Csikszentmihalyi, 2000). It is a branch of psychology hence using the same systematic approaches for investigating psychological phenomena which makes it a science despite contrary believes (Stanovich, 2009). As earlier mentioned, ever since world war two up until the beginning of this decade the main focus within the field of psychology has been on psychopathology. PP arose as a complementary view with a contrary focus to the traditional psychology namely on mental health and human well-being (Seligman & Csikszentmihalyi, 2000).

**Hedonia.** Hedonia, sometimes referred to as SWB, is one of the two classic traditions within PP studies. Because of the disagreement on the operational definitions of the segments of well-being there is no clear distinction between SWB and hedonia (Ryan & Huta, 2009). Though according to Deci and Ryan (2008) an accurate designation of hedonia would be PA and NA. Hence, the presence of hedonic well-being would only be higher
levels of positive emotions and lower levels of negative emotions without attention to satisfaction with life evaluation since such evaluation requires involvement of cognitive interpretations (Deci & Ryan, 2008). SWB on the other hand accounts primarily for people’s individual subjective experience of their lives including both emotions and cognitions in all parts of their existence (Diener, 2000). PA is the extent to which an individual experience feelings of alertness, activation, and enthusiasm. Low PA reflects fatigue and lack of motivation as well as sadness while high PA is characterized by energy, concentration, and engagement. NA is the experience of distress and undesired engagement in aversive moods, that include contempt, anger, disgust, fear, nervousness, and guilt, which increases with enhanced NA. Low NA is a state of serenity and calmness (Watson, Clark, & Tellegen, 1988). Developed by Watson et al. (1988) is the Positive and Negative Affect Schedule (PANAS) which is a self-report measurement for assessing the affective state of a person. The scale has been analyzed and Sandin et al. (1999) found it to be valid, reliable (internal consistent) as well as to possess cross-cultural validation.

**Eudaimonia.** Aristotle (4th century B.C.E/1925) was the first one to differentiate between hedonia and eudaimonia and described the latter as “the good life” (Kashdan et al., 2008). Eudaimonia could be phrased as being the best version of oneself by engaging in virtuous activities. Humans would flourish and function fully through the pursuit of eudaimonic notions (Aristotle, 4th century B.C.E/1925).

Eudaimonic well-being as being a part of PWB have been conceptualized as consisting out of six dimensions and the following are elaborations of these six constituents. Autonomy is interdependence and self-determination as well as avoidance of social evaluation. Environmental mastery is the competence and mastery in management of the surrounding environment. Personal growth is the sense of continuance in development, expansion of new experiences, and self-improvement. Positive relations with others is satisfying relationships in which there is trust, intimacy, empathy, and understanding.
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Purpose in life is long term goals and belief in the past and present meaning of the own existence. Self-acceptance is acknowledgement and acceptance of the self including bad and good characteristics (Ryff, 2014).

**Neuroscientific Assessments for Measuring Well-Being**

The neuroscientific approach to studying well-being is novel (Kringelbach & Berridge, 2009). Previously the human psyche was mainly studied through observation of behavioral outcome and self-report measures (Davidson, 2004; Deci & Ryan, 2008). But as the technology of our time evolves so does the scientific measurements used to study psychology and well-being (Urry et al., 2004).

Neurophysiological studies conducted on nonhuman primates have introduced various detailed properties of the prefrontal cortex (PFC). Neuroimaging and neuropsychological studies on humans have in addition provided further information on task conditions under which the PFC is engaged (Miller & Cohen, 2001). Moreover, electrophysiological studies on asymmetric cerebral activation integrated with self-report results were inferred to be a reliable assessment for measuring dispositional affective states. In addition, this means of measuring asymmetric brain activity could be a reputable traitlike index (Davidson, 2004).

Within neuroscience the underlying brain mechanisms of a fully functioning individual have been explored through usage of various brain measurements such as magnetic resonance imaging (MRI), functional MRI (fMRI), electroencephalography (EEG), and positron emission tomography (PET) (Davidson, 2004; Gazzaniga, Ivry, & Mangun, 2009). MRI is a scanning technique using radio waves and a magnetic field to produce a meticulous image of the brain. The fMRI scan is an advancement of MRI technique wherein metabolic signals can be detected in blood flow during performance of cognitive tasks by a subject (Gazzaniga, Ivry, & Mangun, 2009). EEG registers the
spontaneous electrical currents generated by synaptic activity of the cerebral cortex using electrodes taped to the scalp. The electrodes measures cohesive electrical potentials which are produced by wide settlements of neurons. This results in sustained recording of the overall cerebral activity i.e. an electroencephalogram (Urry et al., 2004). When subsequently discussing brain asymmetry, studies on EEG asymmetry will be primarily employed due to a wide range of articles concerning the topic (Davidson, Pizzagalli, Nitschke, & Putnam, 2002; Coan & Allen, 2003; Sutton & Davidson, 1997) and good internal consistency reliability and test-retest stability shown through correlation studies on EEG asymmetry and self-report measures (Sutton & Davidson, 1997). Like fMRI the PET technique measures blood flow to record the neuronal activation but as both of these measurements are hemodynamic techniques they exhibit limited spatial and temporal resolution (Cabeza & Nyberg, 2000).

Functional neuroimaging techniques that are noninvasive can be categorized into two sections. One is electromagnetic techniques representing EEG, event-related potentials, and magnetoencephalography, to mention some, and the other is hemodynamic techniques such as fMRI and PET. While the former have eminent temporal resolution of a few milliseconds but bad spatial resolution of several centimeters, the latter has great spatial resolution of a few millimeters and poor temporal resolution of several seconds. Both techniques are useful for different devotions but even though they can identify brain areas associated with specific cognitive tasks they cannot establish the essentiality of a region for the exertion of a given task (Cabeza & Nyberg, 2000). These measurements are used for measuring the neural correlates of well-being through integration with subjective self-reports (Urry et al., 2004).

**Neural Correlates of Well-Being**

There is not only one specific neural circuit or brain structure underlying human mental well-being but several mechanisms (Urry et al., 2004). These mechanisms are a
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composition of neural functions that operate together in order for an individual to obtain optimal functioning (Davidson, 2004). The scientific research on the cerebral substrates of well-being is in its early establishment. Thus, no particular neural circuit of well-being have yet been discovered and only a mere part is understood about the neuroanatomy underlying well-being (Urry et al., 2004).

Several studies have concluded that relative greater left than right prefrontal brain activity pattern is correlated with an approach-oriented behavior as opposed to withdraw-oriented behavior, which has on the contrary showed to be related to relative greater right than left sided prefrontal cortical activation (Davidson, 2004; Sutton & Davidson, 1997). In some contexts this phenomenon is referred to as positive versus negative outlook believed to be a result of greater relative left than right sided activation (Urry et al., 2004). Researchers are however not unanimous regarding this matter, some say that the positive attitude owing to greater left side activation is a result of the approach-oriented behavior (Harmon-Jones & Sigelman, 2001; Sutton & Davidson, 1997).

Davidson (2002, 2004) claims that affective style matters a lot to well-being and he gives a detailed insight in the brain structures involved. Affective style refers to the consistent differences in individuals as to their response to the same emotional incentives. It has to do with adaptive emotional responding and how we typically behave accordingly in various situations (Davidson, 2004). ‘Affect’ is sometimes used interchangeably with ‘emotion’ but regardless of which word used they represent the same mechanism. Davidson (2004) explained that through neuroimaging and brain lesion studies the brain mechanisms involved in emotion and affective style have been traced down to a few more significant structures: Dorsolateral prefrontal PFC, ventromedial PFC, orbitofrontal cortex (OFC), amygdala, hippocampus, anterior cingulate cortex (ACC), and insular cortex among others. These are the most involved functions but the core components are suggested to be the PFC and the amygdala (Davidson, 2004; Davidson & Irwin, 1999). The role of hippocampus is of
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significance in the context-modulation of emotional behavior. According to Davidson (2004) what manifests itself in depression is not a case of dysfunctional emotion but instead inappropriate displaying of normal emotions in the wrong context.

Ryff & Singer (2008) implies that there are some neural correlations of eudaimonic aspects of well-being. Ryff, Singer and Love (2004) found personal growth and meaning in life to be correlated with less cortisol in older women. Furthermore, using objective measures of sleep it was discovered that those individuals with more sophisticated environmental mastery had easier falling into REM sleep and stayed in REM sleep longer. Longer REM sleep was also connected to higher levels of positive relationships (Ryff et al., 2004).

The Impact of Weather on Mental Well-Being

Included in the term ‘weather’ are many different aspects such as temperature, windiness, sun time, rain etc., all of which have been researched in connection to wellbeing. The exploration of how well-being is affected by the weather have provided contradictory findings (Beecher et al., 2016). One such study conducted by Kööts, Realo and Allik (2011) using multilevel random coefficient modeling analyses measured two groups of participants, one group of students and the other one with elderlies. The participants’ moods were recorded on seven randomly determined occasions per day for 14 consecutive days and hourly weather data were obtained for the same period. Before the experiment participants had completed one personality test and one test measuring affective states (PANAS). It was found in this study that the weather does have an effect on wellbeing in the sense of affect but that age is a significant mediator for the influence of weather on emotion. Whether emotions were affected by the weather or not was also influenced by being outdoors. Fatigue was detected to be present in cold and dark weather conditions. The study suggests that temperature is weakly related to affective states (Kööts et al., 2011). However Connolly (2013) indicates that temperature matters to happiness and that high temperatures reduce
well-being, while stress and fatigue decrease with low temperature and well-being is increased. In this article the Princeton Affect and Time Survey was used to analyze SWB in relation to weather conditions. The survey was conducted in the summer and states that lifesatisfaction decreases with rain (Connolly, 2013). As for the relationship between sun time and well-being, mental health distress seems to increase during seasons with reduced hours of sun time and vice versa (Beecher et al., 2016).

Several studies have found no relationship between any kind of weather condition and mental health (Beecher et al., 2016). Phelan and Phelan (2017) did not find any correlation between temperature and mental health, and as did not Watson et al., (1988). However, the American Psychological Association (2016) advocates that lack of sunlight, especially in wintertime, affects depressive symptoms. Findings on the impact of weather on well-being are diverse but there seems to be dominant support for solar influence on mental health (Beecher et al., 2016).

**Solar Influence on the Brain**

Findings suggest that sun time is the most persistent predictor of all meteorological aspects affecting well-being (Beecher et al., 2016). There can be health consequences due to lack of sunlight than can cause depression (Rosenthal et al., 1984), or due to solar overexposure which can cause tanning addiction (Kourosh et al., 2010). Light from the sun entering the brain through the eyes is what steers the human sleep/wake cycle. The circadian cycle is not only vital for survival but for our mental health as well (Reppert & Weaver, 2002).

**Circadian cycle.** Daylight from the sun is what regulates the human internal “clock” that is measured on a scale of 24 hours (Hasegawa & Arita, 2014). This clock is the circadian rhythms, also referred to as the sleep/wake cycle, which manifests itself outwards regulated by an internal timing system. Located in the anterior hypothalamus lies the SCN
which is the core of the circadian system that controls the circadian programme. There is a visual pathway, the retinohypothalamic tract (Brainard et al., 2001), ranging to the SCN from the retina which entrain (synchronize) the circadian rhythm according to the solar day and the ways the SCN clock finally produce rhythms in physiology and behavior (Reppert & Weaver, 2002). Moreover, a neural pathway range from the SCN to the pineal gland. When the light-dark cycle entrain neural activity in the SCN, that in turn entrains a rhythmic secretion of the hormone melatonin from the pineal gland (Brainard et al., 2001). Melatonin is synthesized from the neurotransmitter serotonin which is present in the pineal gland (Klein et al., 1997). Melatonin secretion is low during daytime and high during the night (Brainard et al., 2001). If the eye is exposed to sudden light during nighttime there is an increase in serotonin and a decrease in melatonin causing less somnolence (Klein et al., 1997).

Entrainability and regularity are the two requirements upon which the circadian rhythm relies to attain dependable synchronization to the environment. Entrainability synchronize periodic stimuli (sunlight) with internal time whereas regularity oscillate with an exact period. Coexistence of the two mechanisms is hard since better entrainability benefits higher sensitivity which could sacrifice regularity. The solar effect on entrainability depends on the fluence or wavelength together with the phase of stimulation. A circadian clock is prevalent in organisms ranging from bacteria to humans. Regularity and entrainability constitute major characteristics preserved in all circadian clocks, which strongly indicates that the two qualities are essential for survival (Hasegawa & Arita, 2014).

Abnormalities in the SCN resulting in dysfunction of circadian regulation can be caused by lack of sunlight lead to the affective disorder SAD. Other mood disorders related to dysfunction of circadian rhythm are bipolar disorder and major depression. Both disorders are mainly characterized by abnormal social, appetite, and sleep/wake rhythms. Moreover, depression is more common in parts of the world that receive smaller amount of
sunlight over longer periods. In the same areas of the world two to out of five percent of the population suffer from SAD (McClung, 2007).

**Seasonal affective disorder.** SAD is a disorder with symptoms resembling those of depression. SAD is however related to changes in seasons and most commonly occur during the winter when sun hours are fewer (American Psychological Association, 2016). In popular speech SAD is often referred to as winter depression (American Psychiatric Association, 2017) and is characterized by periodic depression during the same season annually (Rosenthal et al., 1984). The symptoms of this disorder are the following: Feelings of sadness, loss of interest in once enjoyed activities, changes in appetite (typically overeating), feelings of guilt or worthlessness, concentration problems, suicidal thoughts, increase in restless activities, energy loss, and change in sleep (typically too much sleep) (American Psychiatric Association, 2017).

Since the disorder is a result of circadian dysfunction most commonly caused by lack of sunlight, one of the treatments used to cure SAD is light treatment (Rosenthal et al., 1984). Bright light therapy is a beneficial treatment in case of SAD but also against depression. It is a non-pharmaceutical treatment where the eyes are exposed to light of suitable duration and intensity, at convenient time of the day (Terman & Terman, 2005). The treatment involves being in front of a light therapy box in the morning for more than 20 minutes (American Psychiatric Association, 2017). When the light hits the retina and ultimately suppress melatonin release somnolence disappears (Brainard et al., 2001). By doing so desirable effects on affective states and sleep can be obtained. Light therapy can serve as adjunct to or instead of antidepressants. The lamp used must possess certain features in order to be efficient. Features such as lamp type, filter, heat emission and positioning are important (Terman & Terman, 2005).

Another mental deficit caused by the sun is tanning addiction (Kourosh et al., 2010) which has not yet been classified as an addiction but matches the criteria for addictive
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behavior (Warthan, Uchida, & Wagner, 2005). Tanning addiction, however, is a result of excessive solar exposure (Diffey, 1991) as opposed to lack of sunlight as featured in the case of SAD (Rosenthal et al., 1984).

**Tanning addiction.** In Diffey (1991) tanning is described as a desirable consequence, i.e. a fashionable behavior. Tanning is in its essence delayed pigmentation of the skin following unfiltered sunlight exposure. There is immediate pigment darkening and delayed tanning which is the sought after effect by sunbathers (Diffey, 1991). Immediate pigment darkening is transient darkening of the skin that shows within five to ten minutes and fades after one to two hours. This kind of tan can be elicited by UVA or visible radiation (Rosen, Jacques, Stuart, & Gange, 1990). The delayed tan on the other hand becomes visible one to two days after appearance in the sun and gradually enhances for several days. This type of tan can last for weeks or even months (Diffey, 1991).

According to Kourosh et al. (2010) tanning can be addictive. Heckman et al. (2008) explored the behaviors and thoughts amongst university students to figure out predictors for tanning dependence and found that variables such as skin-type and ethnicity among others could be correlated to tanning addiction. In Fell et al. (2014) it is stated that the origin of UV addiction would be mediated by β-endorphin an action of hedonia, and withdrawal anhedonic effects. The addiction is comparable to other addiction disorders and is suggested to be similar to substance-related disorders (Warthan et al., 2005).

Awareness of skin cancer caused by UV light increases among people but so does cutaneous malignancies (Armstrong & Kricker, 2001). According to Fell et al. (2014) it is yet unclear whether sunseekers keep exposing themselves incautiously to UV irradiations as a result of fashion for looking tanned or if it is because of actual underlying neurological mechanisms causing an addiction. Although some results have begun to display support for tanning as an addictive behavior (Fell et al., 2014). These studies have shown that unhealthy
UV exposure meets the Diagnostic and Statistical Manual of Mental Disorders (DSM) 4 criteria for substance-related disorders with regards to UV (Kourosh et al., 2010; Petit et al., 2014; Warthan et al., 2005). In alcohol addiction, experimental results imply that alcohol interferes with endogenous opioid mechanisms that are tightly united to dopamine transmission and increase in \(\beta\)-endorphin release (Herz, 1997) not unlike what has been discovered to occur in addiction to UV (Fell et al., 2014). Furthermore, subjects accustomed to sunlight through tanning were able to distinguish true UV from false UV in blind tanning studies (Feldman et al., 2004). Tanning as a neurological addiction could explain why people put themselves up to the risk of getting melanoma (Fell et al., 2014). Moreover, a study conducted on college students found that 30 percent of those who use indoor tanning met the Cut down, Annoyed, Guilty, Eye-opener (CAGE) criteria and 40 percent met the DSM 4 criteria for addiction. Those students who met the criteria of both scales also reported more exertion of substances like alcohol and marijuana as well as symptoms of anxiety than those who did not meet the criteria (Mosher & Danoff-Burg, 2010).

Dermatologists have reported numerous cases where their patients have not managed to stay away from indoor tanning despite suffering malignant melanoma (Petit et al., 2014). Two types of scales have been proposed by Warthan et al. (2005) for diagnosing addiction to UV light and to what degree the addiction extends. These criteria depict symptoms like lack of control, cravings, and proceeding of the behavior regardless of negative outcome. A tantamount to withdrawal can be detected when individuals who expose themselves to UV light excessively experience negative emotions or anxiety if they do not tan as required. There is however no contemporary concordance on a definition of the concept nor any guidelines for therapeutic treatment of the pathology (Petit et al., 2014).

In order to understand an addiction the underlying brain mechanisms of addictive behavior is necessary to address. What manifests itself in an addiction is a dysregulation of
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the reward system (Koob & Le Moal, 2001) in which the neurotransmitter dopamine plays an important role (Berridge & Robinson, 1998). The neuroactive chemical dopamine is involved in many different basic functions in the brain such as emotional states and cognition. One of the roles of dopamine is its involvement in the circadian rhythm where it acts as a chemical messenger for light adaptation. The salubrity of dopaminergic neurons relies on their receiving light driven synaptic inputs. However, several drugs connected to addiction, such as cocaine and amphetamines, act through dopaminergic neurons (Witkovsky, 2004).

**Neural substrates of addiction - dysfunction of the reward system.** The mesolimbic reward system is a pathway deep within the brain which all addictive substances affects (Leshner, 1997). The pathway projects from the ventral tegmental area to the nucleus accumbens (NAc) (Haber & Knutson, 2010; Nestler & Carlezon, 2006) and have connections to the OFC and the limbic system. Activation of the mesolimbic reward system seems to be what makes an addiction proceed (Leshner, 1997). It is a dopaminergic pathway where release of the neurotransmitter dopamine into the NAc regulates the cognitive processes of desire and motivation towards rewarding stimuli. The reward stimulus could for example be food, sex, or substances of abuse (Berridge & Robinson, 1998) (or as in this case potentially sunlight).

Studies on electrical stimulation of specific cerebral sites in mice conveyed the discovery of the anatomically recognizable reward circuit. The cortical-basal ganglia circuit appears to be the center of this system. Reward is a crucial component in learning, in displaying appropriate responses to stimulus, and in the development of goal-oriented behaviors (Haber & Knutson, 2010).

Addiction develops within the brain through solicitation of various sources of reinforcement, by neuroadaptive mechanisms, and dysregulation of the reward circuit due to neurochemical changes (Koob & Le Moal, 2001). In the early stage of addiction dopamine
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is crucial for acute reward, while in the end phase of addiction it is primarily a result of neuronal adaptations in the orbitofrontal glutamatergic (glutamate= major excitatory neurotransmitter) and anterior cingulate projections to the NAc (Kalivas & Volkow, 2005).

PET and fMRI studies display that PFC activity can be recruited by a variety of rewards, both primary hedonic rewards such as pleasant sensations and secondary rewards such as monetary gains (Haber & Knutson, 2010). Kalivas and Volkow (2005) found that in drug addiction plasticity leading to pathophysiology in excitatory transmission decreases the ability of the PFC to execute control over seeking drugs and to commence responsive behaviors to biological rewards as well as makes the PFC hyperresponsive to stimuli that predicts drug availability. This results in an over-physiological glutamatergic drive of the NAc in which excitatory synapses have a decreased ability of neurotransmission regulation.

To sum up, in drug addiction neural plasticity caused by adaptation foster addicts compulsive drug seeking through decrease of the value of natural rewards, thus reducing cognitive control and inflating glutamatergic drive as a response to stimuli associated with drugs (Kalivas & Volkow, 2005). Addiction is an orbit of dysregulation within the reward system that grows progressively and these changes within the brain is what can cause non success of relapse impediment (Koob & Le Moal, 2001).

Possible Neural Correlates of Weather and Well-being

Cerebral asymmetry. Support for the approach/withdraw-oriented behavior rather than positive/negative affective states in correlation with left and right sided cortical activation is found in a transcranial direct current stimulation study conducted by Kelley, Hortensius and Harmon-Jones (2013). The participants’ frontal cortical activity were manipulated on either left or right hemisphere. The individuals who received right hemisphere manipulation, and hence were induced with relative greater right side PFC activation, also reported greater rumination than those individuals manipulated in the left
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hemisphere. Together with results from previous studies Kelley et al. (2013) propose that in association with anger, greater left side activation would predict aggressive actions (approach-oriented) whereas greater right side activation would predict inhibited rumination (withdraw-oriented) (Kelley et al., 2013). Another study supporting the previous results was conducted by (Harmon-Jones & Sigelman, 2001).

Urry et al. (2004) found that, beyond approach/withdraw-oriented behavior, relative greater left PFC activation is related to higher levels of both eudaimonic well-being and hedonic well-being. They also underscore the significance of goal-directed approach behavior for eudaimonia but not for hedonia. Engaging in motivational activities, hence encouraging higher levels of left than right baseline PFC activity, may possibly lead to more experienced well-being (Urry et al., 2004).

By using EEG Coan and Allen (2003) suggest that relative greater right frontal asymmetry cannot be assessed for by withdraw behavior tendencies alone but that there is more complexity to this system. However, their findings on greater left frontal activity is in accordance with previously mentioned results (Coan & Allen, 2003). While other studies using EEG to measure the frontal alpha activity concluded that relative left activity is related to approach behavior and that relative right activity is related to withdraw tendencies (Hosting et al., 2017; Kelley et al., 2013; Urry et al., 2004). Other studies concerning hemispheric asymmetry, with regards to withdraw- and approach oriented behavior, that were conducted on children found that as early as in infants anterior asymmetry can predict response to maternal separation (Davidson & Fox, 1989). One study screened the relationship between low-grade inflammation and resting EEG asymmetry in how childhood maltreatment is correlated with inflammation. Found was that resting EEG asymmetry with greater right prefrontal activation is correlated to inflammation but only for those individuals who endured maltreatment in their childhood. Possible consequences following low-grade inflammation is for example coronary heart disease (Hostinar et al.,
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Gotlib, Ranganath and Rosenfeld (1998) investigated Davidson's (1993) findings regarding EEG asymmetry studies and found, in line with the hypothesis, hypoactivation of left frontal hemispheric activation in depressed subjects (Gotlib et al., 1998).

The hemispheric asymmetry is especially present in the PFC but the brain structure is a key component in emotion and emotion regulation regardless of hemispherical dominance. Together with the PFC the amygdala is emphasized to be important in affective style (Davidson, 2004).

**The role of prefrontal cortex and amygdala.** The PFC and the amygdala are believed to play key roles in the central circuitry of emotion (Davidson, 2002). Davidson and Irwin (1999) claims that emotion guides action accompanied by organization of behavior towards prominent goals. To implement this it is important that the organism can represent emotion in the absence of direct incentives (Davidson & Irwin, 1999) such as reward and/or punishment (Davidson, 2002). Affective style is important in the mental health of humans since it inflect on memory, foster decision making, has an impact on learning, and supply motivation for action when facing environmental elicitors (Davidson, 2002).

The PFC is a neocortical brain structure and it is most developed in primates (animals with flexible and colored behavior). Its assemblage of interconnected neocortical divisions sends and receive information to and from all cortical sensory systems, several subcortical structures, and motor systems (Miller & Cohen, 2001). The role of the PFC for the human psyche is of huge significance. It is responsible for the most complex cognitive abilities in humans and regulates emotions, thoughts and actions (Arnsten, 2009). However, with higher abilities in cognition comes more adverse effects (Arnsten, 2009; Miller & Cohen, 2001). There are divisions of the PFC that are responsible for different parts of affective processing as well as in diverse aspects of emotion regulation (Davidson, 2002).
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With regards to positive and negative affective states important to human mental health, besides the PFC, the amygdala is a brain structure important in dispositional emotional processing. The role of amygdala in emotional processing is especially in conditioned fear but is significant to negative emotional processing and in negative affect as well (Davidson, 2004). It also plays a crucial role in cue-specific fear expression (Davidson, 2002). Over and above these functions, the amygdala have been shown to be crucial in perceiving emotional cues as well as in producing emotional responses (Davidson & Irwin, 1999).

Additional Biological Research - Indirect Solar Effects on Mental Health

Whereas the direct effects of the sun on the brain such as the circadian sleep/wakecycle are vital (Hasegawa & Arita, 2014) the indirect effects are pressing too (Petit et al., 2014). Indirect weather effects on well-being can occur for different reasons (Beecher et al., 2016). Everything from falling trees blocking the road because of a storm (Chongvilaivan, Taniguchi, & Rabanal, 2016) to skin cancer (Mosher & Danoff-Burg, 2010) are believed to affect happiness negatively. Since solar effects on mental health constitute the most consistent findings regarding weather and well-being (Beecher et al., 2016) further emphasis will be put on the biological effects of the sun on humans as in direct influence over mental well-being.

Ultraviolet radiations and the skin. The human species rely on the sun for our mere existence and very survival. The infrared rays from the sun is an important part of the photosynthesis, our eyes respond to the sun’s terrestrial spectrum, and the sun keeps us warm. However, the harmful effects of the sun are almost exclusively within the ultraviolet spectrum from the sun (Diffey, 1991). When rays from the sun hit the human body they induce reactions in the skin (Ichihashi et al., 2003).

UVB radiation is the minority component of solar light that reaches the surface of the earth and is the most effective irradiation to cause melanoma (Pfeifer, You, & Besaratinia,
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The main cause of skin cancer appears to be obtained by repeated sun exposure from childhood (Armstrong & Kricker, 2001). Mutation in epidermal cells are what leads to the development of cancer cells. Three effects on the skin from UVB are appreciated to jointly produce cancer tumors in the human skin: UVB suppress immune reactions, induces tolerance to antigens, and through intracellular signal transduction pathways it upregulates gene expression (Ichihashi et al., 2003). There are two types of normal responses the skin can adopt as an effect of UVR, chronic effects and acute effects. The former is of long duration and gradual onset while the latter is of short duration and rapid onset. An acute injury in the skin following exaggerated sun exposure occurs when erythema (sunburn) emerge. There is an increase in blood volume of the skin when superficial blood vessels dilates and thus cause the redness of the burnt skin (Diffey, 1991). Because of stratospheric ozone reduction the UV radiation from the sun becomes increasingly harmful to the human skin. Besides the risks of catching melanoma chronic sun exposure can lead to photoaging which is the process in which the skin ages in response to UV radiation. The consequences following photoaging are wrinkles, fragile skin, impaired wound healing, lack of recoil capacity, and blisters (Scharffetter-Kochanek et al., 1997).

In Elwood and Jopson (1997) several articles regarding whether occupational or periodic sun exposure evokes more cases of melanoma were investigated. They came to the conclusion that those who are intermittently exposed to the sun are in greater risk of melanoma. This conclusion is supported by (Armstrong & Kricker, 2001). In English, Armstrong, Kricker and Fleming (1997) it is implied that the relation between types of skin cancers and sun exposure to the human skin is complex, though they too found the same evidentiary support for non-occupational heightened risk of melanoma. The p53 gene is an antigen protecting multicellular organisms from gene mutation and thus against cancer. When this gene is mutated by UV light the tumor-suppressor disappears causing skin cancer (Ziegler et al., 1994).
Vitamin D. The main function of vitamin D for humans is to preserve calcium homeostasis (balance). This is accomplished through an increase in efficiency of the intestine that absorbs dietary calcium. When the bodily request for calcium is in imbalance with calcium consumed through diet the vitamin D convey this information to the osteoblasts which in turn communicates to osteoclast precursors to mature and dissolve calcium kept in the bone. Therefore, vitamin D is essential for growth, development, and maintenance of sound skeleton throughout life. For over 750 million years vitamin D have been made in the earliest of life forms which makes it one of the most antique hormones (Holick, 2003). The primary source of vitamin D is UVB irradiations for most people (Grant & Holick, 2005) but it is also asserted that vitamin D can be accessed from eating fatty fish (Chapuy et al., 1997).

When the UVB rays from the sun hit the human skin vitamin D is implemented into the body (Bogh, Schmedes, Philipsen, Theieden, & Wulf, 2010). Chapuy et al. (1997) conducted a study made on participants selected from 20 different cities in France investigated the prevalence of vitamin D insufficiency in normal adults and found it to be rather high. Where there an inadequate amount of vitamin D because of too little sun exposure the subjects food intake did not provide them with the vitamin either. Hence, the article mentions that it is important to notice this insufficiency and prevent it with supplements. Chapuy et al. (1997) also attend the difference between vitamin D ‘insufficiency’ and ‘deficiency’, since the former can have a biological effect on skeletal metabolism and calcium homeostasis (physiological stability/balance) and could lead to bone fragility (Chapuy et al., 1997), while the latter is cause of rickets in children, and osteoporosis, osteopenia and fractures in adults (Holick & Chen, 2008). Although not all researchers differentiate the two concepts (Thacher & Clarke, 2011).

Discussion

The aim of this thesis was to explore how weather affects well-being neurologically. In order to investigate this an insight into the contemporary science of well-being,
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definitions of the concept, and neurological underpinnings was first presented. Thereafter existing literature regarding weather and well-being was displayed and followed by solar impact on the brain. An insight into the brain mechanisms underlying the circadian cycle has been provided as being a crucial solar effect on humans. Neural substrates of addiction was accounted for as a possible explanation for tanning addiction. In an attempt to find weather influences on the brain other than solar effects, possible neural correlates of the weather and well-being are searched for and exhibited. An additional biological framework with indirect solar effects on mental health was integrated to further emphasis solar effects on well-being.

A central finding in this thesis are the neural correlates of well-being, where the brain structures PFC and amygdala have been found to play crucial roles (Davidson, 2002) together with hemispherical asymmetry (Davidson, 2004; Kelley et al., 2013). As for the the aim to find neurological explanations for how weather can affect well-being the result is somewhat indistinct. Regarding weather and mental well-being the only consensus is the sun’s influence over mental states (Beecher et al., 2016). The weather condition sunshine affects the brain directly (Hasegawa & Arita, 2014; Rosenthal et al., 1984) but no other meteorological phenomena was found to influence neural mechanisms.

Investigated first was if weather affects humans mentally. Judging by existing literature weather does seem to have some influence over well-being (Beecher et al., 2016; Connolly, 2013). However, different studies on the matter have explored different meteorological phenomena with different types of measurements (Connolly, 2013; Kööts et al., 2011). Moreover, many of these studies have reached different conclusions regarding the same weather condition in correlation with well-being (Beecher et al., 2016). While Kööts et al. (2011) found temperature to be weakly linked to well-being, Phelan and Phelan (2017) did not find that to be true. Since most studies that have analyzed weather impact on mental health have done so through correlation studies using self-reports and meteorological data, the self-report measures could ironically be influenced by some other
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variable than the weather (Connolly, 2013). Sun and well-being appear to be the only somewhat consistent meteorological variable affecting human mental welfare (Beecher et al., 2016). This would make sense since Kööts et al. (2011) found fatigue to be correlated with dark and cold conditions. Taking into account that the only neurological support there is for weather affecting well-being is solar impact on the brain (Rosenthal et al., 1984; Terman & Terman, 2005) it is not surprising that the most consistent finding have been solar influence.

Regarding well-being and neuroscience articles that mention weather impact on subjects as a confounding variable biasing self-reports (e.g. in Davidson (2004)), they seldom provide more information on this statement in my experience. Leaving much for interpretation I would personally imagine meteorological impact to be of hedonic nature given that the subject is immediately affected by the weather of the day. Keeping this in mind, the support for immediate solar influence on well-being weakens. As explained in Brainard et al. (2001) the neurological effects from the sun are mostly long-term, as in the case of SAD which is a seasonal disorder and not a case of day to day mental illness caused by the lack of sun. The circadian rhythm depends on the sunlight, but the sunlight can be replaced by a lamp providing or causing the same neural effect (American Psychiatric Association, 2017). If the only neurological support there is for solar influence over the brain is either vital for survival (circadian cycle) or long term (SAD), then these aspects are unlikely to be the underlying cause affecting the hedonic well-being of a subject and in turn biasing his or her self-report.

Although in my opinion, just because a neural connection cannot be drawn between well-being and weather at the moment it does not mean that weather cannot influence mental states. There may still be a neurological explanation for this that has not yet been discovered. Personally I notice a huge difference in my mood depending on the weather. I become happy when the sun is shining and feel quite low when it is cloudy and dark. When I was staying
with my aunt in Dubai, where the sun is out almost every day, I felt a higher more stable baseline level of happiness. I had more energy and motivation overall despite having almost no social interactions and being away from my boyfriend. Since I have been to Dubai many times before my conclusion is that the positive mood was due to the sun and not because I was traveling or alike. Supporting this is that I enjoy life more and feel happier wintertime in Sweden on sunny days as well. Even though this subjective experience of mine does not provide any evidential support for meteorological impact on the brain and mental states, it explains why I believe sunlight to instantly influence my mood.

At least in Sweden there can be other possible variables causing positive effects on humans when the sun comes out. I can for example imagine children to be more social and hence happier thanks to playing outside with other kids instead of being inside. Maybe teenagers go out to do sports together and experience more positive emotions thanks to both exercise and social interactions. Adults may feel higher states of PA on picnics together with friends or when having drinks at an outdoor seating. The list can be made long but the common denominator for these variables is that the experienced higher levels of happiness is not due to direct sunlight but rather because of the opportunities for joy-bringing events that comes with for example higher temperatures. These are indirect solar effects on mental states which is not what I interpret is meant when saying that the weather can bias self-reports. Aside from this the weather can in my speculation, as mentioned before, have a purely behavioral effect on the human mind whether it is direct or indirect.

It has been discovered that depression is more common in parts of the world that receive smaller amount of sunlight over longer periods of time (McClung, 2007). Being one of those countries it is not surprising that the citizens of Sweden make use of dry and warm weather conditions when they appear. I think that sunlight can be an important indirect aspect of eudaimonia. In my understanding the weather can affect four out of the six dimensions of eudaimonic well-being. I would argue that autonomy, environmental mastery, personal
growth, and positive relations with others can be affected. As explained above, relationships can in my opinion flourish in warmer degrees. I can imagine personal growth to be damaged because of rain since people tend to stay inside, thus they may not experience new things. The autonomy of people to decide for themselves what they would like to do can be interrupted by for example falling trees on the road caused by storms. Environmental mastery can become difficult when the environment is constantly changing as it does in Sweden. These aspects can in worst case contribute to a depression, thus altering structures in the brain but neither this is support for meteorological instant influence on the brain.

Well-being is not just the absence of negative affect and/or mental illness but the presence of positive emotions and life satisfaction (Seligman & Csikszentmihalyi, 2000). With regards to this, what is currently understood about the impact of weather on mental health rather suggest that it has an influence over mental illness than it has an effect on mental well-being (American Psychological Association, 2016; Beecher et al., 2016). For example social relationships are, as mentioned earlier, important to well-being (Ryff, 2014) and withdraw-oriented behavior can harm such conduct. The two mental disorders related to the weather, SAD and tanning addiction, are both characterized by withdraw behavior (American Psychiatric Association, 2017; Petit et al., 2014).

When comparing brain areas involved in depression and the neural structures involved in SAD they differ. In depression there is greater right then left frontal alpha asymmetry as shown by EEG measures (Davidson, 2004) whereas in SAD the function of the SCN is abnormal (Rosenthal et al., 1984). In my understanding this indicates that the two mental pathologies are distinct and hence provides some support for the sun affecting the mental health of humans. Though, since the sunlight regulating the internal clock can be temporarily replaced with man-made light the hypothesis is yet again challenged.

Discussing the possibility of tanning addiction it is plausible that it can affect the brain and mental health in two ways, immediately and long-term. Immediate (direct) effects
is solar stimuli satisfying hedonic well-being and adding to the addiction, whereas long-term (indirect) effects are the downsides of the addiction. The puzzling thing about tanning addiction is that even some of those individuals who are diagnosed with skin cancer caused by solar overexposure do not stay away from the sun. I would say that this is quite convincing support for the tanning addiction hypothesis. Such indirect effects on human mental wellbeing like malignant melanoma (Ziegler et al., 1994) or vitamin D deficiency (Chapuy et al., 1997) are in my opinion not reasons for claiming that the weather would affect self-reports. Nor are either biological condition directly related to brain functions and hence give no additional support for the sun (or any meteorological phenomena) affecting the brain.

There are at present no neurological studies on meteorological impact on well-being. One can speculate why that is and personally I believe that there are too many possible confounding variables that complicate such studies. Behavioral studies using self-reports can provide information on the topic to some extent but underlying neurology connected to different weather conditions can be hard to find. To be able to conduct such studies in the future and maybe find neurological correlations between mental health and the weather an increase of studies in the research area needs to be done according to my knowledge.

**Limitations and Future Directions**

The limitations of this thesis have mostly been regarding the restricted amount of studies on how weather affects well-being. Another limitation was the complete lack of neurological studies on the topic. Because of these constraints there are few comparable results, thereof the choice to angle this thesis to solar influence on the brain. The majority of the studies used in this thesis on weather and well-being have been conducted on westerners which inflicts poor generalizability and limits the results. For future directions a thought is to conduct more studies on weather and well-being in other countries outside the West. Studies could be carried out in Bali, for example, where the average temperature is 27 degrees the whole year with the difference in seasons being rain periods. Such experiments could
possibly provide more information about other meteorological impact on well-being than that of the sun. Moreover, all of the existing studies have been correlational, thus it would be interesting to use other research designs as well as to replicate the existing studies to invigorate the results.

This thesis may raise more questions than it answers but those are important questions since the weather is something we are constantly and unavoidably surrounded by. Making this thesis a literature review was necessary in order to investigate the existing information about the topic, despite the presented limitations. This area of research could however benefit from experimental studies trying to find neurological explanations for meteorological influence over mental states. Such studies would be hard to carry out because it is difficult to establish whether the mental states are caused by the weather or by something else. Additionally, neural correlation studies on this subject would be troublesome to conduct with contemporary assessments. A questionnaire asking people if they think that weather affects well-being could have been integrated into this thesis as an interesting addition to the literature search.

Regarding problem with operationalizations, conceptualizations, and definitions of well-being, more research on the underlying brain mechanisms of well-being can help categorize the constituents of well-being. The more that is uncovered about neural correlates of well-being the easier to comprehend and use the term in a correct manner. Davidson (2004) propose that to determine the underlying brain areas of cognitive, emotional, and behavioral mechanisms additional studies on lesion patients, and research on cognitive abnormalities and neurological disorders are crucial.

At the present only hedonic well-being can be measured objectively. What is supposed about meteorological conditions biasing impact on self-reports is that the subject is affected by that days’ weather, which would be a hedonic influence. If that is the case then maybe meteorological impact on the brain can be objectively measured in the future.
Conclusion

Contemporary research on how the weather affects well-being provide diverse and inconsistent findings (Beecher et al., 2016). What is currently known about meteorological impact on mental health is that there is solar influence upon the brain (Beecher et al., 2016; Rosenthal et al., 1984). The sun regulates the circadian rhythm (an internal sleep/wake cycle) which is crucial for survival (Hasegawa & Arita, 2014). The circadian clock is orchestrated by the brain architecture SCN. Lack of sunlight can cause dysfunction of the SCN and result in the mental disorder SAD (American Psychological Association, 2016). Overexposure however, can cause an addiction to tanning (Heckman et al., 2008) which possibly could lead to malignant melanoma and potentially death (Diffey, 1991). The sun can have other biological indirect effects on mental well-being caused by vitamin D deficiency, since the primary source of vitamin D is provided to us by sunlight (Grant & Holick, 2005).

The findings in this thesis indicates that there is no strong relationship between weather and well-being. There was no support for any neural correlates of temporary meteorological impact on well-being overall. The sun affects the brain but the impact on mental states is long-term and would hence not bias a self-report in that sense. However, it is debatable whether the sun can influence eudaimonic well-being in some cases. Although due to lack of objective ways to measure eudaimonic well-being it is difficult to know. In case those individuals addicted to tanning actually possess the brain abnormalities of those who are addicts to other substances of abuse, there would be stronger support for solar influence on hedonic well-being.
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